Ergonomic DHM Systems - Limitations and Trends – A Review Focused on the 'Future of Ergonomics'

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Abstract

Ergonomic Digital Human Model (DHM) systems have evolved from drawing templates to complex and Computer Aided Engineering (CAE) integrated design and analysis tools. While the development of DHM for other domains (e.g. the game sector) has seen significant progress in recent years, advances of DHM in the area of ergonomics have been comparatively modest. As a consequence, we need to question if current DHM systems are fit for the future. According to Dul et al. (2012), future characteristics of Human Factors and Ergonomics (HFE) can be assigned to six main trends: (1) global change of work systems, (2) cultural diversity, (3) ageing, (4) information and communication technology (ICT), (5) enhanced competiveness and the need for innovation, (6) sustainability and corporate social responsibility. Based on a literature and internet review, we systematically investigate the capabilities of current ergonomic DHM systems versus the 'Future of Ergonomics' requirements.
DHMs already provide broad functionality in support of trends (2) and (3), and more limited options in regards to trend (1). However the growing importance of ICT (4), the need for innovation (5) and sustainability (6) are addressed primarily from a hardware-oriented engineering perspective and not reflected in DHMs, demonstrating a persistent separation between hardware design (engineering) and software design (information technology) in the view of DHMs. This disconnection needs to be overcome in the era of software-defined user interfaces and mobile devices.
The design of a mobile ICT-device is discussed to exemplify the need for a comprehensive future DHM solution. Designing such mobile devices requires an approach that includes organizational aspects as well as technical and cognitive ergonomics. Multiple interrelationships between the different aspects result in a challenging setting for future DHM.
In conclusion, the 'Future of Ergonomics' poses particular challenges for DHM in regards to the design of mobile work systems, and moreover mobile information access.

Keywords: Megatrend, Ergonomic future trend, Digital Human Model, Holistic model

1. Introduction

Ergonomic design of new products and production systems requires thorough consideration of human anthropometric and biomechanical characteristics. In early times this was achieved by means of a trial and error, sometimes random and stepwise evolutionary re-design of products. This obviously ineffective and inefficient process demanded for an alternative approach. Knowledge from the Arts provided first data for estimating body dimensions, shape and postures. Standardized data collection and presentation provided a valuable first step towards systematic design (Knussmann, 1988), which was followed by the successful introduction of anthropometric drawing templates (Juergens et al., 1985). They were applicable for technical drawings. With the growing distribution and importance of computer-aided design (CAD) and computer-aided engineering (CAE), the first ergonomic digital human modeling (DHM) systems were developed and applied shortly afterwards (Alexander, 1995; Chaffin, 2005; Muehlstedt et al., 2008). Today, DHM mostly model human anthropometry and biomechanics to facilitate amongst others, vision, reach, and comfort analyses. Moreover DHM model human workload and performance, allowing for planning and optimization of workplaces and production processes. However, DHM predominantly appear to focus on the physical aspects of product and workplace.
As an alternative to ergonomic digital human models, DHM were developed independently in multiple other domains. Human factors and

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psychology research led to the development of sophisticated cognitive models. Furthermore, virtual humans were developed in the domain of computer-graphics and allowed a photo-realistic simulation of human appearance and behaviors, serving a quickly growing demand from the computer games and movie industries.
Bridging the gap, it is important that ergonomic DHM systems meet future demands as well, excluding a limitation to the status quo as an option. It is therefore important to identify and understand the future trends in Ergonomics, their impact on DHM, and determine how current ergonomic DHM research complies with these trends.

2. Methods

2.1. Future trends for ergonomics

Trend analyses were selected arbitrarily and exemplarily from recognized authors, based on expert assessment. The number of trend analyses for products or services is legion. This paper does not claim to be comprehensive and address each and every trend. Instead, a macroscopic perspective is chosen, and only "megatrends" are addressed. According to Naisbitt (1982), "megatrends (…are) large social, economic, political, and technological changes (…), they influence us for some time – between seven and ten years, or longer)". These megatrends serve as a first basis for future requirements that need considered when preparing for the next generation of ergonomic DHM systems.

2.1.1. General trend studies and compendia

Although several trend studies appear to be aged, their results are still valid today. Previously identified trends were for example the transition from industrial to information societies, from technology push to technology pull, or from national economies to a global marketplace (Naisbitt, 1982). A glance at the ongoing development shows that these trends have materialized, and that they are mostly still ongoing. An actual trend study identifies seven new "megatrends" for the following 20 years (Roland Berger strategy consultants, 2011). These trends are:

- Changing demographics (incl. world population, aging societies and urbanization),
- Globalization and future markets (incl. importance of exports, emerging commercial markets - BRIC)
- Scarcity of resources (incl. energy, water and other commodities),
- Challenge of climate change (incl. increasing CO_2 emissions, global warming and ecosystems at risk)
- Dynamic technology development (incl. technology diffusion, innovation, life sciences),
- Global knowledge society (incl. education, decreasing gender gap, war for talent)
- Sharing global responsibility (incl. global cooperation, NGOs, philanthropy).

Most of the trends have been addressed by national or international research programs already in many ways. One characteristic of all megatrends is that their formulation is relatively vague. Therefore, variability becomes an essential element and actions to comply with the trends have to be flexible and adjustable. This flexibility in responding to the trend is itself subject to the dynamic technological development, so that the speed of innovation is essentially driving a rapid adjustment of actions and products.

2.1.2. The future of ergonomics

In 2003, the International Ergonomic Association established a technical committee (TC) on the Future of Ergonomics. Its results have been published recently by Dul et al. (2012). They provide more detailed information about the impact of megatrends on the domain of human factors and ergonomics (HFE) and provide a future perspective for the human factors/ergonomics (HFE) discipline and profession. In general, HFE takes a systems approach, is design-driven und focuses on human well-being and performance. The global trends that are of special interest to HFE are:

1. Global change of work systems,
2. Cultural diversity,
3. Ageing,
4. Information and communication technology (ICT),
5. Enhanced competitiveness and the need for innovation,
6. Sustainability and corporate social responsibility.

Especially in economically advanced systems, work systems have shifted significantly towards a service economy. Consequently, service production and human-computer interaction will be emphasized. In parallel, economically developing countries have extended their manufacturing base. The need for tools to support cost-effective planning and design of related workplaces is based on these trends.
With reference to cultural diversity, products and production services that seek a global market need to consider different users; manifesting a diverse set of cultural backgrounds, different characteristics and aspirations, which all have to be considered appropriately.
A major development is caused by demographic change. This trend primarily addresses aging as an important factor influencing the design of products and production systems, including age-related

human characteristics impacting on design requirements and solutions. However, this trend is not global and primarily observed for economically developed countries.
According to Moore’s law, computing power doubles each year (Moore, 1965). This leads to new opportunities and forms of work, especially in the service industry. The trend likewise involves enhanced means of communication, unlimited information access and location-independent collaborative work systems. Mobile ICT devices have a particularly high impact on work systems and lead to new requirements for ergonomic design and evaluation.
Enhanced competitiveness and the need for innovation is a trend that relates to rapid innovations cycles and the speed of the design process. Moreover, it evidences a need for fast, efficient and effective methods and tools of designing, planning and producing products and services. These are essential for future market success.
Sustainability and corporate social responsibility refers to the attention not only for natural and physical resources, but also for human and social resources. This trend is beyond purely legal responsibilities and refers to a high value of human well-being. HFE will work on combining profit with sustainability and social responsibility, as defined by Jastrebowski, the founder of the term “Ergonomics”, in 1857.

2.2. Literature search

A literature search was carried out in the Web of Science database for keywords “Digital Human Modelling” OR “DHM”, limited to publications in the last 10 years (2003-2013). Only peer reviewed publications with full text online were included, and newspapers, reviews and theses were excluded. The search yielded 2,136 results. This catalogue was further reduced to publications with subject term “Ergonomics”, and language “English”, which reduced the results to 99. Those ninety-nine publications, predominantly journal publications (97), were then screened for a trend analysis. Consequently five publications were excluded from further analysis, as they were inappropriately labelled. The full list of selected publications can be retrieved from the authors. A total of 94 publications were accessed and analyzed.

3. Results – Ergonomic DHM and future trends

From the content of publications, the following 12 categories were derived as main classifiers and taxonomy of publications (Table 1). At the highest level, several large groups of publications can be further aggregated to the three top categories *General Product Design* (17) with 18% of publications; *Package & Safety*, including aircraft and automotive applications (23), which contributed 24% of publications; and *Production*, including automotive assembly, manufacture in general and production planning (28), accounting for 30% of publications.

Table 1: Main classifiers and count of related publications

Category	Publications
Aircraft package/design	4
Anthropometry	11
Automotive assembly	9
Automotive package/design	15
Automotive design & assembly	3
Automotive safety	1
Biomechanics	4
General DHM	10
Healthcare	2
Manufacture	13
Product design	17
Production planning	3
Workload assessment	2

In the category *Product Design*, only two out seventeen publications considered aspects of cognitive ergonomics, while one publication covered emotion aware design. Most publications in this category related to posture, motion and reach modelling.
Most pamphlets were published in the *International Journal of Industrial Ergonomics* (23), followed by *Applied Ergonomics* (14) and the journal *Human Factors & Ergonomics in Manufacturing* [*& Service Industries]*(9).
It should be further noted that the few future oriented publications, investigating ICT and cognitive aspects of human-product interaction were only recently published in non-mainstream journals, such as the *International Journal of Human Factors Modelling and Simulation* (Thorvald et al., 2012), and a more generally modelling than DHM motivated study in *Universal Access in the Information Society* (Mieczakowski et al., 2013). The study related to emotion aware design, however without a clear relation to DHM, and therefore a candidate for exclusion from the review, was published in 2009 in *Applied Ergonomics* (van den Broek & Westerink, 2009).
It becomes apparent from the review that only very few of the developments in ergonomic DHM systems are readily meeting the future trends and developments in all of their facets. Most of the work addresses single trends or is ready to address one. However not all of these trends are new, and several of them have been addressed already.

The megatrends influence ergonomic DHM systems primarily indirectly. Their impact leads to changing requirements for products, which are designed using DHM. Modeling and simulation and, thus, ergonomic DHM systems have already been proven efficient ways for accelerating the design cycle of new products. Therefore, they meet a basic requirement already.

3.1. Trends that are already considered

Ergonomic DHM systems support modeling and simulation of human factors in very early product design phases. They are a valuable tool for accelerating general product design. Therefore, they meet the growing need for enhanced competiveness and innovative products (trend 5 of Dul et al., 2012). The majority of today's ergonomic DHM systems offer sufficient functionality to consider the basic characteristics and variability of different user populations (e.g. EMA, Human Builder, JACK, RAMSIS). This refers to age, gender and nationality. In terms of anthropometry and to a lesser extent biomechanics, DHM are generally ready for trends (2) and (3), however limited to sight and comfort analysis. DHM systems offer basic functions, but do not consider time-variant characteristics due to age, e.g. reduced visual acuity or reduced mobility.

3.2. Trends that are moderately considered

The change of work systems from physical work to cognitive work (1) is a consequence of the development from an industrial to an information society. Yet, most DHM focus on physical workplace design and not cognitive aspects. Modern DHM allow for designing and analyzing general office workplaces, albeit a computer is considered as a piece of hardware equipment positioned in the center of the visual field. The user interface displayed on the computer screen and its design is not yet considered. The same applies to complex displays in vehicles. The separation between hardware design (engineering) and software design (information technology) persists. This disconnection should be overcome in the era of software-defined user interfaces, and thus requires consideration in DHM.

3.3. Trends with deficits

A general shortcoming of today's ergonomic DHM systems is the limitation to a hardware-oriented engineering perspective. Cognitive or social aspects, which are of growing interest in several trends (4,5,6) are not reflected appropriately. There are some isolated solutions addressing these trends, e.g. cognitive models (ACT-R or SOAR), performance models (MicroSaint) or social and cultural DHMs, but they are rarely connected to ergonomic DHM, as reflected in the literature review.

3.4. DHMs in a mobile society with mobile devices

The need for information is one of the core characteristics of the information society. Modern ICT enables information access anytime and anywhere. The increasing commercial success of tablets, smartphones and other mobile devices provides evidence of the huge market demand. Today, digital media are considered to be essential for 72% of the German online public (Telekom, 2013). Nearly 90% of the German population owns a cellphone and 75% do not leave their home without it (BITKOM, 2013). Actual trends at consumer electronics tradeshows and fairs show that smartphones and tablets are increasingly integrated into other systems, as for example cars for additional functionality and connectivity.

Consequently mobile devices have to be designed in accordance with HFE principles, including users' characteristics and capabilities. Most manufacturers have identified HFE and user experience (UX) as a key factor for success. Alexander et al. (2008) argued that this requires a holistic approach taking into account the environment and mobile use, as well as hardware and software design. Despite recent developments, user experience is still limited to software design (Lumbsden, 2008; Shneiderman, 2009). As an example, stylesheets give explicit and detailed information about user interfaces, but do not consider hardware design (e.g. Android or Apple style guides).

Although the holistic approach constitutes a theoretical gap, requiring further research and insight, it clearly entails a more comprehensive approach for the design of DHM. In combination with the importance for innovation and increasing speed of new product development (5), the gap may as well impact on the sustainability of a product or service (6). While currently not represented in ergonomic DHM, this novel property may add significant value to the tools.

4. Discussion

4.1. Status of DHM system for mobile HCI design

The information and communication technology trend (4) is exemplarily discussed in regards to mobile device design, as it exposes a deficit in DHM. Mobile HCI design, as it contributes more or less to all future megatrends, is of growing importance. It therefore addresses multiple aspects across domains.

Mobility is not a new application field for ergonomic DHM systems. Many are used for vehicle interior design, and were developed especially for that application. Consequently, they offer multiple functions to support designers and engineers.

Mobile devices though differ from car interior equipment: Apart from combining software and hardware elements, they are generally smaller,

light-weight, and hand-held. Moreover, they are frequently used during user displacement (gait). Each of these characteristics results in different executions of ergonomic design, requiring different functionalities of the DHM design tool.
Some of these requirements are specified in this paragraph.

4.1.1. Anthropometry and biomechanics

Most small mobile devices are hand-held. This evokes that a detailed hand model for both hands is required for (a) holding the device and (b) manual information input. The hand model has to consider anthropometric as well as biomechanical characteristics and their variability. Multiple anthropometric databases are available for this purpose, but only few made their way into ergonomic DHM systems (Endo et al., 2007; Mochimaru et al., 2006).
As a matter of fact, anthropometric dimensions of their hand models are correlated with the overall body dimensions and shape, but do not allow for additional input of more specific data. Hand postures are restricted to a set of standard fingertip or hand grip gestures. Modifications, if possible, often require manual adjustments of each isolated joint. This is time-consuming and cumbersome.
Several designs of detailed hand models have been made available, yet they have not been connected to a full-body model.
A reason why the connection to a full-body model system is so important is the individual movement. Unlike vehicle interior equipment, most mobile devices are used during dynamic body motion, introducing postural change, kinematic links, oscillations and movements with large amplitudes, all affecting biomechanical reactions.
Moreover, most mobile devices are used in an unconstraint environment where further distracting effects exist.

4.1.2. Information processing and cognitive models

Different approaches are known to model human information processing; including perception, cognition and motor responses. Examples of such cognitive architecture models are ACT-R (atomic component of thoughts-rational) and SOAR (state, operator apply result). Most such models cover general characteristics of human cognition and require additional skills for their reasonable application.
Mobile HCI is a challenging topic for cognitive models, because of additional environmental stimuli, individual movements etc., which require parallel processing of multiple tasks. According to the Wickens model of multiple resources, several of these tasks compete for the same resource (Wickens, 1984), reducing overall performance. None of the ergonomic DHM systems available allows for such a close connection between a cognitive model and anthropometric or biomechanical models.

4.2. Potential solutions for ergonomic DHM systems in mobile HCI design

The following paragraph discusses different aspects which a possible future DHM system will have to address.

4.2.1. General approach

Mobile HCI appears to require a joint approach of different ergonomic DHM systems across domains. Improved and expanded anthropometric models are required to design the hardware and device’s outer shape. Biomechanical models allow for considering the effect of individual movement and mobile use. Finally, cognitive models handle information processing during HCI. This multimodal approach is currently not possible. Isolated models for each domain may exist, but a lack of integration and communication prevents further comprehensive analysis.
What could a potential solution look like?
In the first instance, a perception model could identify the target of interest and determine the focus point for the anthropometric model. It would also calculate the effect of distracting environmental stimuli on performance. The anthropometric model while holding the mobile device could determine the body posture. A biomechanical model would simulate resulting postures and forces on the hand-arm-shoulder system from gait movement. Finally, the DHM could transfer the results of reach, posture, and comfort analysis to the cognitive model. This will determine overall user performance as a result of the analysis.

4.2.2. Hardware handling and physiologic effects

Smartphones and tablet computers are usually held with the non-dominant hand. Head and cervical spine pitch are generally larger than in office workplaces (Ritchey et al., 2007; Young et al., 2012). However, holding and operating a tablet computer results in higher physiological strain for several muscles of the hand, wrist and lower arm. Muscular strain might vary because of changing weight and hardware design. First results from an ongoing empirical study support the effect and show higher electromyographic (EMG) activity for these muscles (Conradi et al., 2013). As in many other cases, applying an ergonomic DHM system for the analysis would allow for examining a larger variety of hardware designs in a shorter amount of time.

4.2.3. Mobile GUI: Visualization

Optimal analysis of visualization requires both, anthropometric as well as perceptive/cognitive

studies. A general sight analysis including field of vision and occlusions serves as a basis for a more detailed analysis of information content and GUI design. Conversely and as previously discussed, these properties are usually separated. For mobile GUI design a consistent analysis is important because of the dynamics of the movement; introducing changes of distance between eye and display, and relative movements between display, hand, and eye (Alexander et al., 2008).
Additional movement, environmental stimuli and other factors lead to a 10% decrease in visual performance of GUI (Conradi et al., 2013). As these factors affect GUI design, they need implemented in ergonomic DHM systems.

4.2.4. Mobile GUI: User input

The conclusions on visualization apply to mobile user input as well. In this case the gait induces additional movement which affects input performance and thus, the characteristics of interactive elements. As an example, the effect of gait increases error rate and required time (Alexander et al., 2008).

5. Conclusions

Ergonomic DHM systems have been introduced to various CAx applications. However, they are mostly focused on hardware, technology and workplace design, mainly in the automotive sector. Cognitive models are available, nonetheless often case-specific and generic. By integrating different types of DHM systems in a holistic approach, more comprehensive simulations and analyses during early design phases will become possible, supporting megatrends and future trends in Ergonomics. The holistic approach will increase speed of design for new products and production systems, while empirical research remains time- and labor-intensive. Approaches which are limited to empirical research often do not increase the speed of product design. It is concluded that ergonomic DHM systems will be valuable tools and support the future of Ergonomics, provided current gaps are filled.
An important function to be added to ergonomic DHM is cognition modelling, as well as interfacing or integration of different types of digital human models (Paul & Wischniewski, 2012). In addition, several DHM systems appear to have re-invented the wheel by duplicating or re-formulating solutions from other fields of application. A potential solution to this problem would be to define interfaces or a common bus for information exchange between different DHM, based on the special requirements of the specific application.
By referring to the megatrends described in this paper, future products and developments can be best supported by ergonomic DHM. Likewise, DHM requirements can be formulated and functionalities defined so that current DHM systems are prepared for future challenges and innovations.

Examples of Digital Human Model systems:

ACT-R (Adaptive Control of Thought-Rational) is a cognitive architecture specified by Anderson & Lebiere (1998).
EMA (Editor menschlicher Arbeit) is a DHM system distributed by IMK Automotive. http://www.imk-automotive.de/.
Human Builder is a DHM system distributed by Dassault systems. http://www.3ds.com/.
JACK is a DHM system distributed by Siemens PLM Software, http://www.plm.automation.siemens.com/.
RAMSIS (Rechnergestuetztes Anthropometrisch-Mathematisches System zur Insassen-Simulation) is a DHM system distributed by HumanSolutions. http://www.human-solutions.com/
SOAR (State, Operator And Results) is another cognitive architecture. It has been developed by Laird, Newell & Rosenbloom (1987).

References

Alexander, T, 1994. Analysis of different anthropometric tools for workplace design. Proceedings of the 2nd international congress on physiological anthropology. Kiel: German society of physiological anthropology.
Alexander, T, Schlick, CM, Sievert, A, Leyk, D, 2008. Assessing Human Mobile Computing Performance by Fitts' Law. In: Lumbsden, J. (Ed): Handbook of Research on User Interface Design and Evaluation for Mobile Technology. Hershey, NY: Information Science Reference (IGI-Global).
Anderson, JR, Lebiere, C, 1998. Working memory: activation limitations on retrieval. In Cognitive Psychology (30).
Android developers style (2013). http://developer.android.com/design/style/index.html.
Apple, 2013. iOS 7 Human Interface Guidelines. https://developer.apple.com/library/ios/documentation/userexperience/conceptual/mobilehig/
BITKOM, 2013. Das Handy als staendiger Begleiter. http://www.bitkom.org/de/presse/78290_77337.aspx
Chaffin, D, 2005. Improving digital human modeling for proactive ergonomics in design. Ergonomics, Vol. 48.
Conradi, J, Henrich, T, Westhoven, M, Plegge, C, Nord, B, Alexander, T, 2013. Wearable and adaptable equipment for personal equipment. Internal report, Wachtberg: FKIE.

Dul, J, Bruder, R, Buckle, R, Carayon, P, Falzon, P, Marras, WS, Wilson, JR & van der Doelen, B, 2012: A strategy for human factors/ergonomics: developing the discipline and profession, Ergonomics, DOI:10.1080/00140139.2012.661087.
Endo, Y, Kanai, S, Kishinami, T, Miyata, N, Kouchi, M, Mochimaru, M, 2007: Virtual Ergonomic Assessment on handheld products based on virtual grasping by digital hand. Technical Paper 2007-01-2511. Warrendale: SAE.
Juergens, HW, Aune, I, Erichsen, K, Helbig, K, Pieper, 1985. Theorie und Praxis von Koerperumrissschablonen. Koblenz: BWB.
Knussmann, R, 1988. Anthropologie. Stuttgart: Fischer.
Laird, JE, Rosenbloom, P, Newell, A, 1987. Soar: An architecture for general intelligence. Artificial intelligence, 33(1).
Lumsden, J, 2008. Handbook of research on user interface design and evaluation for mobile technology. Hershey, New York: IGI global.
Paul, G & Wischniewski, S, 2012. Standardization of Digital Human Models. Ergonomics 55 (9). http://dx.doi.org/10.1080/00140139.2012.690454
Mieczakowski, A, Langdon, P, & Clarkson, PJ, 2013. Investigating designers' and users' cognitive representations of products to assist inclusive interaction design. *Universal Access in the Information Society*, *12*(3), 279-296. doi:10.1007/s10209-012-0278-8
Mochimaru, M, Kouchi, M, Miyata, N, Tada, M, Yoshida, Y, Aoki, K, Kawachi, K, Motomura, Y, 2006. Dhaiba: Functional Human Models to Represent Variation of Shape, Motion and Subjective Assessment. Technical paper 2006-01-2345, Warrendale: SAE.
Moore, GE, 1965. Cramming more components onto integrated circuits. Electronics, Vol. 38(8).
Muehlstedt, J, Kaussler, H, Spanner-Ulmer, B, 2008. The software incarnate: Digital human models for CAx and PLM systems. Zeitschrift fuer Arbeitswissenschaft 2/2008.
Naisbitt, J, 1982. Megatrends. Ten New Directions Transforming Our Lives. Warner Books, 1982.
Ritchey, P, Peres, SC & Duffield, TJ, 2012. Differences in Muscle Activity for 4 Touch Devices. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 56 (1), 1594–1598.
Roland Berger Strategy Consultants., 2011. Trendkompendium 2030. http://www.rolandberger.de/expertise/trend_compendium_2030/
Shneiderman, B, 2009. Leonardo's laptop: Human needs and the new computing technologies. Cambridge, MA: MIT Press.
Telekom, 2013. LIFE*, Studien zur Informations- und Telekommunikationsbranche. http://www.studie-life.de
Thorvald, P, Hoegberg, D, & Case, K, 2012. Applying cognitive science to digital human modelling for user centred design. International Journal of Human Factors Modelling and Simulation, 3(1), 90-106. doi:10.1504/IJHFMS.2012.050078
van den Broek, EL, & Westerink, JH D M, 2009. Considerations for emotion-aware consumer products. Applied Ergonomics, 40(6), 1055-1064. doi:10.1016/j.apergo.2009.04.012
Wickens, CD, 1984. Processing Resources in Attention. In: Parasuraman & Davies (Eds). Varieties of Attention. New York: Academic Press.
Young, JG, Trudeau, M, Odell, D, Marinelli, K & Dennerlein, JT (2012). Touch-screen tablet user configurations and case-supported tilt affect head and neck flexion angles. Work, 41 (1), 81–91.